Risk-Based Decisions under Uncertainty for Engineered Infrastructure

CEVE/STAT 313 – Spring 2022
MWF 9:00 AM – 9:50 AM, Ryon Lab, Room 201

Prof. Leonardo Dueñas-Osorio
Professor, Department of Civil and Environmental Engineering, Rice University
6100 Main Street, MS-318, Houston, TX 77005
Ryon Laboratory, Room 212
leonardo.duenas-osorio@rice.edu · (713) 348-5292

Course objectives:

To introduce principles and methods to quantify the effects of uncertainty in decision making for adequate performance of engineered infrastructure. Methods will assist engineers, analysts and stakeholders to design, operate, and maintain complex systems safe.

Students will learn to apply quantitative decision analyses and risk management modeling tools, including deterministic and probabilistic methods, across a variety of practical decision problems in science and engineering. Students will also recognize that the systematic treatment of uncertainty and risk quantification are essential for adequate planning, design, operation, and decision support in the context of engineered systems. It will become clear that uncertainties are unavoidable but manageable through rational decision analysis methods.

Scope:

The course starts with a study of the roles of probability and uncertainty in engineering and their impact on societal decision making. Then, there is a focus on decision theory and analysis, as well as on the Bayesian approach to systematically combine real data with expert judgment. Risk analysis tools, utility theory, game theory, optimization, and infrastructure safety follow next, with an emphasis on practical decisions and the extreme statistics that drive hard decision-making. All mathematical concepts are developed in class and illustrated in the context of real socio-engineering problems and phenomena.

Course calendar by week:

1	**Introduction to decision making under uncertainty and risk management** Course overview, sample risk evaluation studies, rational decision making, and the role of mathematical modeling.	[1] Ch. 1, [2] Ch. 2, [3] Ch. 1, [4] Ch. 1, [5] Ch. 1
2	**Decision theory I** **Martin Luther King, Jr. Day (01/17)** Definitions, risk classifications, decision models, decision trees, decision criteria, and applications to risk assessment and management.	[2] Ch. 2, [3] Ch. 1, [5] Ch. 2, 4

3	**Elements of probability**. **Descriptors of random variables and advanced probability distributions** Random variables, distributions, conditional probability, total probability, and Bayes' formula.	[1] Ch. 2.3, 3.1, [3] Ch. 2, [5] Appendix A
4	Moments of random variables, expectation, characteristic functions, and functions of random variables, random trials, random occurrences, and summary of distributions.	[1] Ch. 3.1-3.2, 4, [3] Ch. 3, [5] Appendix A
5	**Decision theory II** **Midterm recess (02/11)** Decisions based on existing information and prior analyses, decisions based on additional information.	[2] Ch. 2, [3] Ch. 1, [5] Ch. 4
6	Pre-posterior analyses, value of information, sensitivity of decisions to errors.	[2] Ch. 2, [3] Ch. 4, [5] Ch. 4, 9
7	**Utility theory I** **Exam I (02/25)** Axioms of utility theory, utility functions, determination of utility values, decision maker preferences.	[2] Ch. 2, [3] Ch. 4, [5] Ch. 5
8	Utility function of monetary values and other variables, maximum expected utility, sensitivity of expected utility, assessment of probabilities.	[2] Ch. 2, [3] Ch. 4, [5] Ch. 5
9	**Utility theory II** Decisions with multiple objectives, weighted decision analysis, multi-attribute utility theory, outranking methods.	[2] Ch. 2, [3] Ch. 4-5, [5] Ch. 5
10	**Spring break (03/12-03/20)**	
11	**Bayesian approaches** Bayesian discrete and continuous cases, Bayesian sampling theory.	[1] Ch. 9, [2] Ch. 2, [3] Ch. 8, [4] Ch. 2, 10
12	Bayesian estimation, regression, correlation, and hybrid networks.	[1] Ch. 8, 9, [4] Ch. 2, 10, [5] Ch. 9, 12, 17
13	**Exam II (04/08)** **Limit and multivariate distributions. Models for risk assessment** Multivariate distributions, and distribution of extremes.	[1] Ch. 3.3 [2] Ch. 4, [3] Ch. 9, [5] Ch. 8, 11
14	Testing goodness-of-fitness of distribution models for risk quantification.	[1] Ch.7, [3], Ch. 10, [4] Ch. 4-5, [5] Ch. 2, 8
15	**Strategic decision making** Uncertainty and analysis of errors, game theory, Markov	[3] Ch. 5, 10, [5] Ch. 6-10,

	processes, and optimization methods for risk management and decision-making.	15-18, Appendix
16	**Super-homework (during final exam)**	[6]

Course learning outcomes:

Students completing the course should be able to:

1. Make or inform practically optimal decisions by probabilistically evaluating design or improvement alternatives under uncertainty
2. Implement risk evaluation, analysis and control methods for effective risk assessment and management
3. Model natural hazard phenomena with joint and extreme value probability distributions, calculate their moments, and explore functions of random variables
4. Identify types of uncertainty and sources of uncertainty in infrastructure systems affecting practical decision making
5. Perform analysis and quantification of errors in infrastructure performance prediction
6. Identify, classify, model, assess and report orally and in writing decision making processes

Reading material:

[1] Ang, Alfredo H.-S., and Wilson H. Tang, (2006). *Probability concepts in engineering – Emphasis on applications to civil and environmental engineering*. 2nd Ed. New Jersey: John Wiley & Sons, Inc.

[2] Ang, Alfredo H.-S., and Wilson H. Tang, (1990). *Probability concepts in engineering planning and design – Volume II: Decision, risk and reliability*. New Jersey: John Wiley & Sons, Inc.

[3] Jordaan, Ian, (2005). *Decisions under uncertainty – Probabilistic analysis for engineering decisions*. Cambridge, UK: Cambridge University Press.

[4] Rausand, Marvin, (2011). *Risk Assessment – Theory, methods and applications*. Hoboken, New Jersey: John Wiley & Sons, Inc.

[5] Haimes, Yacov Y., (2004). *Risk modeling, assessment and management*. 2nd Ed. Hoboken, New Jersey: John Wiley & Sons, Inc.

[6] Hammond, J.S., R.L. Keeney, and H. Raiffa, (1999). *Smart Choices*. New York: Broadway Books, Random House, Inc.

On-line resources:

Course material and video lectures shared via Canvas.
Relevant scientific journals:

- ASCE/ASME Journal of Risk and Uncertainty in Engineering Systems
- International Journal of Risk Assessment and Management
- Journal of Behavioral Decision Making

- Journal of Multicriteria Decision Analysis
- Journal of Risk and Uncertainty
- Reliability Engineering and System Safety
- Risk Analysis
- Structural Safety

Course grading:

Homework	20%
Examination I	25%
Examination II	25%
Super-Homework	30%

Academic honor code:

The Honor System embodies the concept of personal honor in a framework of law and practice. To quote the Constitution, Rice students are placed on their honor by the group "not to violate the trust placed in them in any way."

The result is a system of conducting examinations, writing papers, and performing other academic endeavors with regard for individual honor and without faculty proctoring. Thus, the responsibility for maintaining the validity of academic work is placed on all students.
Website: http://honor.rice.edu/

Disabilities:

Any student with a documented disability needing academic adjustments or accommodations is requested to speak with me during the first two weeks of class. All discussions will remain confidential. Students with disabilities will need to also contact Disability Support Services in the Ley Student Center.

Absences:

Students are expected to attend all lectures. Planned absences must be communicated to the instructor in advance of the event. Forced absences of unforeseen character must be discussed with the instructor as soon as practical after the event. Appropriate courses of action are determined on a case-by-case basis.

Office hours:

- Wednesdays from 1:00 PM – 2:00 PM: Prof. Dueñas-Osorio, Ryon Lab., Room 212
- TBA: TA Xiangnan Zhou, 2 hours, Ryon Lab., Hallway/Room 203